

Final Report

13 Jun 2000

Title: GaN MISFETs

PI Name: Dimitris Pavlidis, Professor EECS

Address: The University of Michigan

Department of Electrical Engineering

and Computer Science

1301 Beal Ave.

Ann Arbor, MI 48109-2122

Phone number: (734) 647-1778

Fax Number: (734) 763-9324

Email address: pavlidis@umich.edu

Award Number: N000149910513

Web site: www.eecs.umich.edu/dp-group

DISTRIBUTION STATEMENT A

Approved for Public Release

Distribution Unlimited

Long term goals: Microwave signal amplification at high power levels exceeding those achieved with currently available GaN Heterostructure Field Effect Transistor Technology

Objectives:

Conduct experimental and theoretical studies to demonstrate and analyze the advantages offered by AlN/GaN MISFETs:

- » MOCVD Growth of high-quality AlN/GaN heterostructures
- » Simulate AlN/GaN MIS structures and MISFETs
- » Develop high-power AlN/GaN MISFETs and Amplifiers
- » Characterize DC, low- and high-frequency, and power performance of AlN/GaN MISFETs

Approach:

- Evaluate the crystalline quality of AlN/GaN heterostructures and in particular AlN through XRD
- Determine the electrical properties of MISFETs through Hall characterization and evaluate optimum designs for normal and inverted AlN/GaN heterostructures
- Study the low-frequency properties of AlN/GaN MISFETs and determine interface state properties and dispersion effects and their impact on small and large-signal device properties
- Fabricate micron and submicron AlN/GaN MISFETs devices
- Optimize the DC, small-signal, and power characteristics of AlN/GaN MISFETs through simulation and experimentation ⇒ determine optimum MISFET layer structures
- Design, fabricate, and characterize high-power MISFET amplifiers

20010116 079

Work Completed:

- Evaluated the crystalline quality of AlN/GaN heterostructures and in particular AlN through XRD
- Determined the electrical properties of MISFETs through Hall characterization
- Determined the interface state properties of AlN/GaN MISFETs
- Fabricated micron AlN/GaN MISFETs devices
- Simulated the DC characteristics of AlN/GaN MISFETs

Results:

- XRD of MISFET structure shows distinctive AlN peak ($d_{AlN} = 12\text{nm}$) indicating good crystalline quality
- AlN thickness was varied between 5 and 18nm to maximize electron mobility
- Hall mobility of overall MISFET (GaN channel and thin AlN barrier) structure increases with decreasing AlN thickness up to $\mu = 320\text{cm}^2/(\text{Vs})$ for 11nm AlN
- The necessary process for AlN/GaN MISFETs was developed and applied to heterostructures grown by MOCVD
- The DC, low-frequency, high-frequency and small-signal characteristics of AlN/GaN MISFETs were studied experimentally and the results demonstrate good electrical performance.
- AlN/GaN MISFETs $2\mu\text{m}$ -long gates demonstrated I_{DSS} of 700mA/mm and extrinsic g_m of 136mS/mm
- AlN/GaN MIS demonstrate good C-V characteristics corresponding to low interface states density of $\sim 10^{11}\text{cm}^{-2}\text{eV}^{-1}$
- Modeling and characterization confirms extremely low heterostructure interface density

Impact/Applications:

- Development of high power III-V Nitride MISFETs operating at high frequency responds to the needs of future generation multifunctional electromagnetic systems envisioned by the Navy and DoD
- The devices studied under this program will allow to increase the performance of radar, electronic warfare and communications systems through improved power characteristics at high frequencies.

Transitions: N/A**Related Projects:** N/A**References:** N/A

Publications (Names of books, chapters, or significant papers as a result of award):

- [1] A. Eisenbach, E. Alekseev and D. Pavlidis
Growth and Characterization of AlN/GaN HFETs
Ninth Biennial Workshop on Organometallic Vapor Phase Epitaxy (OMVPE '99), Ponte Vedra Beach, Florida, May 23-27, 1999, Session X, Devices II
- [2] E. Alekseev, A. Eisenbach, D. Pavlidis
Power Performance of AlGaN/GaN HEMTs with 0.2 to 1mm Gate Widths
Proceedings of the 23rd *Workshop on Compound Semiconductor Devices and Integrated Circuits* (WOCSDICE '99), Chantilly, France, May 1999, pp. 121-122
- [3] E. Alekseev, A. Eisenbach, D. Pavlidis
MOCVD Grown AlN/GaN HFETs
Proceedings of the 23rd *Workshop on Compound Semiconductor Devices and Integrated Circuits* (WOCSDICE '99), Chantilly, France, May 1999, pp. 129-130
- [4] E. Alekseev, D. Pavlidis, N. X. Nguyen, C. Nguyen, and D. E. Grider
Large-Signal Characteristics of AlGaN/GaN Power MODFETs
1999 *IEEE MTT-S International Microwave Symposium Technical Digest*, Anaheim, CA, June 13-19, 1999, Vol. 2 , pp. 533-536
- [5] E. Alekseev, A. Eisenbach, D. Pavlidis
Interface Properties and Electrical Characteristics of III-V Nitride-Based MISFETs
European Gallium Arsenide and Related III-V Compounds Application Symposium(GAAS99), Munich, Germany, pp. 168-171, October 4-8, 1999
- [6] E. Alekseev, A. Eisenbach, D. Pavlidis
Low Interface State Density AlN/GaN MISFETs
Electronics Letters, November 1999, Vol. 35, No. 24, pp. 2145-2146
- [7] S.H. Hsu, P. Nguyen-Tan, D. Pavlidis, E. Alekseev
Frequency Dependent Output Resistance and Transconductance in AlGaN/GaN MODFETs
Proceedings of the International Semiconductor Device Research Symposium, Charlottesville, VA, December 1-3, 1999
- [8] A. Eisenbach, E. Alekseev, S.M. Hubbard, and D. Pavlidis
Growth and Characterization of AlN/GaN MISFETs
Proceedings of the 24th *Workshop on Compound Semiconductor Devices and Integrated Circuits* (WOCSDICE '00), Aegean Sea, Greece, Session 8, May 2000

Patents: N/A

REPORT DOCUMENTATION PAGE

Form Approved
OMB NO. 0704-0188

Public Reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comment regarding this burden estimates or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.

1. AGENCY USE ONLY (Leave Blank)	2. REPORT DATE 6/13/00	3. REPORT TYPE AND DATES COVERED Final	
4. TITLE AND SUBTITLE GaN MISFETs		5. FUNDING NUMBERS C: N000149910513	
6. AUTHOR(S) Dimitris Pavlidis, Andreas Eisenbach and Egor Alekseev			
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) The University of Michigan, EECS Department, 1301 Beal Ave., Ann Arbor, MI 48109-2122		8. PERFORMING ORGANIZATION REPORT NUMBER ONR-00-1	
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) U. S. Army Research Office P.O. Box 12211 Research Triangle Park, NC 27709-2211		10. SPONSORING / MONITORING AGENCY REPORT NUMBER	
11. SUPPLEMENTARY NOTES The views, opinions and/or findings contained in this report are those of the author(s) and should not be construed as an official Department of the Army position, policy or decision, unless so designated by other documentation.			
12 a. DISTRIBUTION / AVAILABILITY STATEMENT Approved for public release; distribution unlimited.		12 b. DISTRIBUTION CODE	
13. ABSTRACT (Maximum 200 words) XRD characterization of MISFET structures showed distinctive AlN peaks ($d_{AlN} = 12\text{nm}$) indicating good crystalline quality. The AlN thickness of the I-layer was varied between 5 and 18nm to maximize the electron mobility. The Hall mobility of the overall MISFET (GaN channel and thin AlN barrier) structure was found to increase with decreasing AlN thickness up to $m = 320\text{cm}^2/(\text{Vs})$ for 11nm AlN. The necessary process for AlN/GaN MISFETs was developed and applied to heterostructures grown by MOCVD. The DC, low-frequency, high-frequency and small-signal characteristics of AlN/GaN MISFETs were studied experimentally and the results demonstrate good electrical performance. In particular, AlN/GaN MISFETs 2 μm -long gates demonstrated IDSS of 700mA/mm and extrinsic gm of 136mS/mm. Moreover, AlN/GaN MIS demonstrate good C-V characteristics corresponding to low interface states density of $\sim 10^{11}\text{cm}^{-2}\text{eV}^{-1}$			
14. SUBJECT TERMS semiconductor devices, high power, widebandgap semiconductors		15. NUMBER OF PAGES	
		16. PRICE CODE	
17. SECURITY CLASSIFICATION OR REPORT UNCLASSIFIED	18. SECURITY CLASSIFICATION ON THIS PAGE UNCLASSIFIED	19. SECURITY CLASSIFICATION OF ABSTRACT UNCLASSIFIED	20. LIMITATION OF ABSTRACT UL

GENERAL INSTRUCTIONS FOR COMPLETING SF 298

The Report Documentation Page (RDP) is used for announcing and cataloging reports. It is important that this information be consistent with the rest of the report, particularly the cover and title page. Instructions for filling in each block of the form follow. It is important to **stay within the lines** to meet **optical scanning requirements**.

Block 1. Agency Use Only (Leave blank)

Block 2. Report Date. Full publication date including day, month, and year, if available (e.g. 1 Jan 88). Must cite at least year.

Block 3. Type of Report and Dates Covered.

State whether report is interim, final, etc. If applicable enter inclusive report dates (e.g. 10 Jun 87 - 30 Jun 88).

Block 4. Title and Subtitle. A title is taken from the part of the report that provides the most meaningful and complete information. When a report is prepared in more than one volume, repeat the primary title, and volume number, and include subtitle for the specific volume. On classified documents enter the title classification in parentheses.

Block 5. Funding Numbers. To include contract and grant numbers; may include program element number(s) project number(s), task number(s), and work unit number(s). Use the following labels:

C - Contract	PR - Project
G - Grant	TA - Task
PE - Program Element	WU - Work Unit
	Accession No.

Block 6. Author(s). Name(s) of person(s) responsible for writing the report, performing the research, or credited with the content of the report. If editor or compiler, this should follow the name(s).

Block 7. Performing Organization Name(s) and Address(es). Self-explanatory.

Block 8. Performing Organization Report Number.

Enter the unique alphanumeric report number(s) assigned by the organization performing the report.

Block 9. Sponsoring/Monitoring Agency Name(s) and Address(es) Self-explanatory.

Block 10. Sponsoring/Monitoring Agency Report Number. (if known)

Block 11. Supplementary Notes. Enter information not included elsewhere such as; prepared in cooperation with....; Trans. of...; To be published in.... When a report is revised, include a statement whether the new report supersedes or supplements the older report.

Block 12a. Distribution/Availability Statement.

Denotes public availability or limitations. Cite any availability to the public. Enter additional limitations or special markings in all capitals (e.g. NORFORN, REL, ITAR).

DOD - See DoDD 4230.25, "Distribution Statements on Technical Documents."

DOE - See authorities.

NASA - See Handbook NHB 2200.2.

NTIS - Leave blank.

Block 12b. Distribution Code.

DOD - Leave Blank

DOE - Enter DOE distribution categories from the Standard Distribution for unclassified Scientific and Technical Reports

NASA - Leave Blank.

NTIS - Leave Blank.

Block 13. Abstract. Include a brief (*Maximum 200 words*) factual summary of the most significant information contained in the report.

Block 14. Subject Terms. Keywords or phrases identifying major subject in the report.

Block 15. Number of Pages. Enter the total number of pages.

Block 16. Price Code. Enter appropriate price code (NTIS only).

Block 17. - 19. Security Classifications. Self-explanatory. Enter U.S. Security Regulations (i.e., UNCLASSIFIED). If form contains classified information, stamp classification on the top and bottom of the page.

Block 20. Limitation of Abstract. This block must be completed to assign a limitation to the abstract. Enter either UL (Unlimited) or SAR (same as report). An entry in this block is necessary if the abstract is to be limited. If blank, the abstract is assumed to be unlimited.

REPORT DOCUMENTATION PAGE (SF298)
(Continuation Sheet)
